II SECA Industry Teams

II.1 Development of a Low-Cost 10-kW Tubular SOFC Power System

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Objectives

- Design a common low-cost generator to meet all chosen markets.
- Develop an anode-supported micro-tubular cell capable of twice the power density presently achieved.
- Design, build, and test an inverter with 94% efficiency for conversion from direct current (DC) to alternating current (AC).
- Test prototype of a natural gas fueled unit meeting and exceeding Solid State Energy Conversion Alliance (SECA) goals.

Approach

- Remove precious metals from anode connection brazes which are stable and conductive in the necessary operating environment.
- Improve anode conductivity and stability to allow a greater power per unit length of cell tube.
- Decrease solid oxide fuel cell (SOFC) generator component costs through advanced manufacturing techniques.
- Develop a control topology utilizing Controller Area Network bus (CANBUS) architecture to decrease overall instrumentation and control cost.
- Develop the AC/DC high-efficiency conversion end building off our existing 98%-efficient DC/DC regulator.

Accomplishments

- **Fuel Cell Power Increased by 33%:** Through the development of an advanced power take-off concept, the Acumentrics Tubular SOFC has resulted in a power increase of 33% over the existing cell design. This has been achieved by a proprietary contact technique allowing power take-off from both ends of the cell tube. This breakthrough results in a reduction in overall cost/kW of the system of approximately 25%.
- **Brazed Electrical Connection Meets SECA Cost Target:** The electrical take-off from the anode of Acumentrics' tubular SOFC had been accomplished prior to this SECA project utilizing a braze material adding over $1,300/kW to the product cost. Under a SECA task, a number of braze materials and mixtures have been tested, with one achieving the necessary performance requirements while only adding $1/kW to the overall system cost, thereby reducing the system cost by over $1,300/kW.
- **Prototype DC/AC Inverter Achieves Over 96% Efficiency:** Acumentrics has developed a DC/DC regulator capable of achieving over 98% efficiency and also prototyped a DC/AC inverter stage that is over

98% efficient. The full system has been verified to achieve over 96% efficiency (excluding transformer), which is above the DOE-sponsored energy challenge requirements.

- **Stable Cell Performance Exceeds 6000-hr Operation:** Demonstrated over 6000 hours stable cell performance with average degradation rate below 0.25%/500 hours, nearly achieving the 2010 Phase III SECA goal of 0.1%/500 hours.
- **Improved Anode Conductivity Increasing Power by 10%:** Cells which had an additional high nickel contact layer added to the inner diameter of the fuel cell tube have shown an improvement of 10% in power over standard cells with current collected at one end of the tube.

Future Directions

- **Evaluate a DC/AC Inverter with Greater Than 95% Efficiency:** By demonstrating the integration of an inverter capable of over 95% efficiency versus the market standard of 82-90%, overall system efficiencies can rise by nearly 5 percentage points. This improvement in overall efficiency can be taken as fuel savings to reduce the overall cost of electricity (COE). Another option is to operate the fuel cell stack at a lower cell voltage point, thereby increasing the individual cell power and decreasing the number of fuel cells required and the overall capital cost.
- **Complete the System Design Capable of Achieving SECA Cost Targets:** The overall system design for a generator capable of achieving SECA cost goals is nearing completion. Upon completion of this design, the detail cost requirements of each subsystem will be validated and a work breakdown structure for each major subsystem will be developed. Trade-offs for performance and cost in each major area will be made to allow for a machine capable of penetration into the largest number of markets.
- **Reduce the Operating Temperature to 650-700×C:** By demonstrating an SOFC equal in performance at 650-700°C to one at 800°C, all materials of construction will reduce in cost dramatically, as will overall size due to reduced amounts of insulation. By reducing the operating temperature to or below 700°C, stainless steel materials can be substituted where only high-temperature alloys were suitable previously, which could result in greater than a six-fold reduction in cost.

Introduction

The Acumentrics SECA project has focused on the design and manufacture of micro-tubular SOFC power systems approaching twice the power density now achieved by state-of-the-art anode-supported tubular designs. These units will be capable of entry into the telecommunication, remote residential, and military markets. Operation on fuels including natural gas and propane will be developed for the telecommunication and remote residential markets. Operation on liquid fuels, including diesel and JP-8, will be developed for the military markets.

Working with Acumentrics to define market segments and market requirements are a number of key investors that are strategic players in their respective markets. They include:

- Chevron Texaco for remote markets and liquid fuels.
- Northeast Utilities and NiSource for integration in the natural gas and electricity infrastructure.
- Sumitomo Corporation of Japan for introduction and product definition into the Japanese market.

Approach

To achieve the final SECA goal of a manufactured unit cost of less than $400/kW, work can focus on increasing cell power, thereby decreasing the number of cells per kilowatt, or it can focus on decreasing the cost of each component. With such an aggressive goal, work must focus on both paths. To increase cell power, work is centered on improved materials as well as enhancements in geometry. Cells with increased anode conductivities to decrease electrical bus losses are being investigated. Improved conductivity of cathodes is also being investigated to decrease the potential loss associated with the electrochemical reaction on the air side. Increases in cell tube diameter as well as

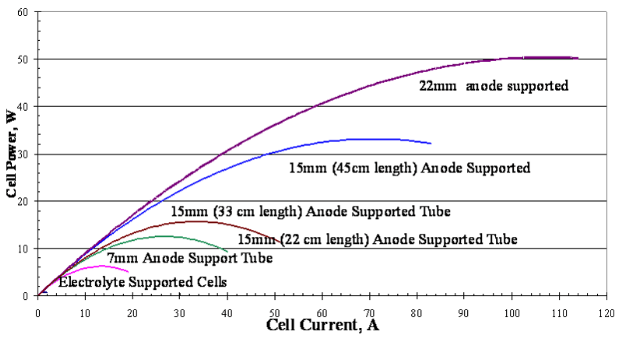

Figure 1. Cell Power Trend

multiple contact points along the length are also being studied.

For subsystem cost reductions, the machine is divided into four major sub-systems: the SOFC generator, the control system, the power conditioning system, and the fuel and airflow system. In the SOFC generator, advanced materials and manufacturing techniques are being investigated, including metal injection molding as well as metal stampings. Vacuum cast insulation to near net shape is also being considered. For the control system, a CANBUS architecture is being developed as well as integration of control of all valves and power electronics. For the power electronics sub-system, the focus is on improving the overall DC/AC conversion efficiency to avoid excessive losses which compromise overall system efficiency and require more cells and therefore more cost. In the air and fuel sub-system, removal of redundant components as well as qualification of equivalent components at lower cost are the paths chosen.

Results

To improve cell power, advancements have been made in the tube anode conductivity as well as connection points. Figure 1 shows the cell power trend with time of the Acumentrics anode-supported design. The first curve represents older designs built on electrolyte-supported tubes producing only 1 W/tube. The technology was then developed to build anode-supported cells, which enabled an immediate increase to 7 W/tube. This 700% jump is a result of two major factors. The first is a decrease in electrolyte thickness from 300 microns to less than 30 microns, which causes a significant reduction in

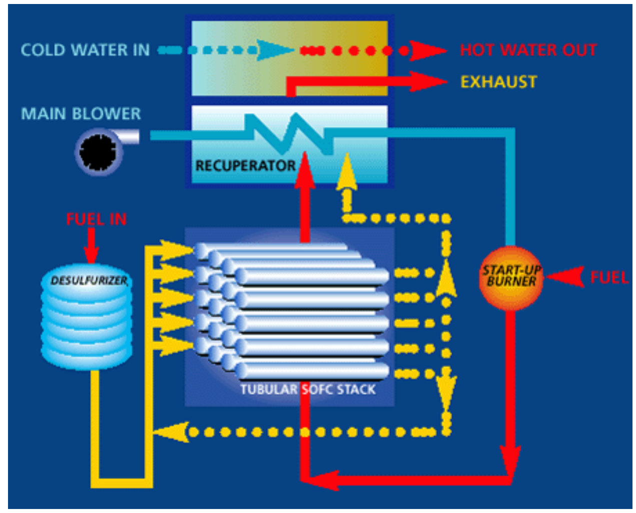

Figure 2. Acumentrics Tubular SOFC Steam Reformed System Overview

cell resistance. The second is an increased anode support thickness, allowing for a lower voltage drop cell bus. The next power increases were geometry-related, allowing 12 W/tube by increasing to 15 mm diameter and then 16 W/tube, which has now increased to 20 W/tube by increasing length. Further work will move to increase the diameter to 20-25 mm with some length increase with an ultimate goal of 50 W/tube.

To improve overall system efficiency, a steam-reformed natural gas fuel system was developed to replace the existing partial oxidation system. This was made feasible by the development of a dual-chamber manifold system that allowed for capture of not only the inlet fuel but also the effluent fuel. This effluent stream provides the necessary water for steam reformation, thereby increasing the overall fuel concentration and system performance. Figure 2 shows the overall system diagram, which shows a percentage of the cell effluent reintroduced with the new fuel while the remaining percentage is combusted to provide preheating for the air stream as well as additional combined heat and power capabilities.

To decrease generator cost, major reductions have been made in braze connection part and material costs as well as recuperator costs. The original Acumentrics design had a brazed connection to the anode for current collection which was made

Figure 3. Cell Braze Cap Development

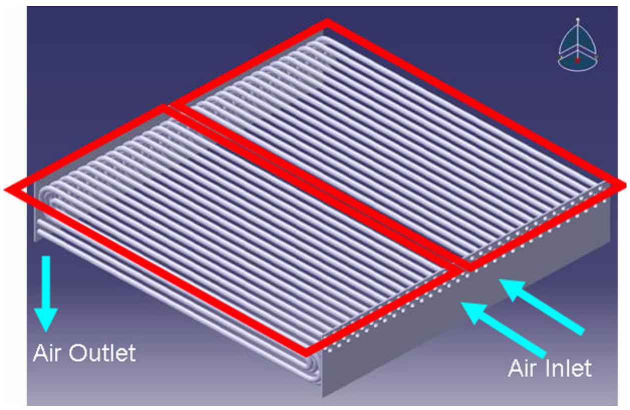

Figure 4. Bent Tube Recuperator Design

with a precious metal braze material. This resulted in a cost of over $1300/kW. Under the first phase of this project, two braze materials have been developed and validated for performance and longevity which are each under $1/kW. The cell itself was brazed to a nickel connection cap machined from solid stock nickel, resulting in a cost of over $6/cell. During the initial phase of this project, a new stamped design was developed which is under $0.65/cell, with further reductions expected. Figure 3 shows the existing and newly developed designs. For recovering the heat from the fuel cell stack, the recuperator design prior to the SECA project was a welded three-pass design of high-temperature super alloys which required welding of over 900 tube ends. A new design has been developed with a lower-cost material consisting of a bent tube geometry, reducing the welding requirements by over 67%. A schematic is seen in Figure 4.

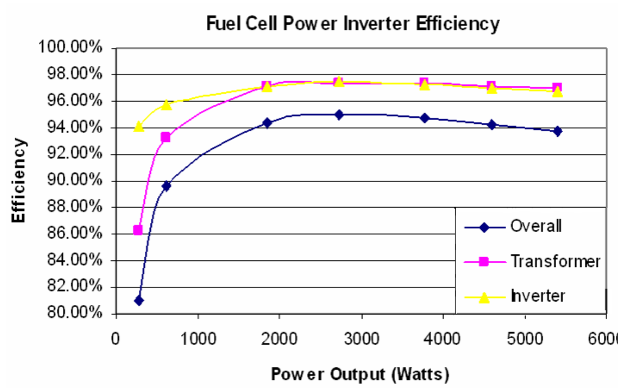

Figure 5. Fuel Cell Power Inverter Efficiency

To boost the overall system efficiency, a DC/AC inverter was developed which has an overall conversion efficiency of over 94%. Figure 5 shows the efficiency and its trend over the 0 to 5 kW level. This unit, when fully developed, has the ability to replace an existing inverter package that is 86-87% efficient. This would then result in a boost in overall generator system efficiency of over 3 points. Another advantage of this design is the usage of many components being developed for the 48 V automotive conversion which is occurring at this time. This will allow for leveraging of the volume cost reductions seen in the automotive industry into the fuel cell industry.

Conclusions

Considerable advancements have been made in the first year of the Acumentrics' SECA project. Cell power advancements have been made exceeding 300%. Cost reductions in certain key fuel cell stack components have resulted in decreases of over $1000/kW. Advances in system efficiency and DC/AC efficiency have also been realized to allow achievement of the SECA performance goals. Further work on all of these tasks will be performed to achieve the ultimate goal of $400/kW.

FY 2004 Publications/Presentations

1. "Status of the Acumentrics SOFC Program", N.F. Bessette, Presented at the Annual SECA conference, Boston, MA., May 11, 2004.